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X-RADIOGRAPHIC ATLAS OF LITHOTYPES AND OTHER STRUCTURES IN THE DEVONIAN SHALE SEQUENCE OF WEST VIRGINIA AND VIRGINIA

By

Edward B. Nuhfer, Robert J. Vinopal and David S. Klanderman

August, 1979

Prepared for

United States Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

NOTICE

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $4.50
Microfiche $3.00

Printed in the United States of America
USDOE Technical Information Center, Oak Ridge, Tennessee

METC/CR-79/27
Distribution Category UC-92

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By

West Virginia Geological and Economic Survey

under

Contract EY-76-C-05-5199

CONTENTS

ILLUSTRATIONS

X-RADIOGRAPH ATLAS OF LITHOTYPES AND OTHER STRUCTURES IN THE DEVONIAN SHALE SEQUENCE OF WEST VIRGINIA AND VIRGINIA

by
Edward B. Nuhfer,[1] Robert J. Vinopal,[1] David S. Klanderman[1]

ABSTRACT

X-radiographs of 525 samples from cored wells and outcrops serve as the basis for a study of fabric elements in the Upper Devonian shale sequence of West Virginia and Virginia. Four shale lithotypes have been identified from X-radiographs: (1) thinly-laminated shale, (2) lenticularly-laminated shale, (3) sharply-banded shale, and (4) non-banded shale. The order from 1 to 4 follows decreasing lateral fabric continuity. Two non-shale lithotypes, siltstones and concretions are also recognized. Gas production from this shale section is associated with lithotypes possessing high lateral fabric continuity. Thus, a classification based on fabric elements appears useful both for interpretation of depositional environments and for interpretation of reservoir properties. Forty-nine illustrations of lithotypes, other sedimentary structures, and tectonic features are given.

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[1] West Virginia Geological and Economic Survey

INTRODUCTION

Fabrics and sedimentary structures in shales have been studied less than those of coarser clastics and carbonates. This is partially due to the lack of interest in shales and the intensely weathered nature of the average shale outcrop. Due to the recent interest in the Eastern Devonian Shales as a gas reservoir, several shale cores were taken and present a rare opportunity to investigate fabric elements in shales of varying stratigraphic units and gas productivity.

Five cores located in western West Virginia and Virginia and one outcrop in eastern West Virginia provided 525 samples (Figure 1). With the exception of the Middle Devonian Marcellus Shale outcrop, all samples are Upper Devonian in age ranging from the Rhinestreet Member of the West Falls Formation up through the Cleveland Member of the Ohio Shale. A listing of stratigraphic units in the cored wells is given in the Appendix. Detailed stratigraphic relationships of the Devonian shale sequence can be found in Schwietering (1979) and Patchen (1977).

X-radiography is a relatively quick and inexpensive technique for maintaining a detailed visual record of a large core sample. Techniques used for cutting radiograph slabs are given in Florence (1979). Slabs were cut to a standard thickness of 2mm. A Field Emission Corporation Faxitron 804 instrument with a 400 watt air-cooled tungsten tube was utilized. An X-ray source to specimen distance of 61 cm produced detailed radiographs. Kodak Type M film was used for its high resolution and short exposure time. A setting of 40 KV and an exposure of 2 minutes produced maximum specimen contrast. The graininess of the film permits enlargements up to 30X by placing the negative in a standard photo enlarger. Contact prints at 1X can be easily made by placing a glass plate over the negative to prevent blurring. Positive prints were made on Kodak Rapid Polycontrast print paper. All positive prints in this report are 1X.

CLASSIFICATION OF LITHOTYPES

Petrologic study and the classification of fine-grained rocks have emphasized composition (Payton and Thomas, 1959; Keller and Ting, 1950; Bates and Strahl, 1957; Davis, 1970; Picard, 1971; and Lewan, 1978 are examples) rather than definition of fabric elements. A number of workers have examined the micro-structure of shales by scanning electron microscopy (see, for example, Heling, 1970; O'Brien, 1970; Gipson, 1965), but examination of such ultrastructure is of little use for general classification of rock types. Harvey and others (1977), however, have made use of larger-scale fabric elements in characterization of shale. In the strata observed in this well, fabric elements which are deduced from simple imaging techniques appear to reveal more contrasts between shale samples than does any single mineralogical, petrophysical, or geochemical parameter (Nuhfer and Vinopal, 1979).

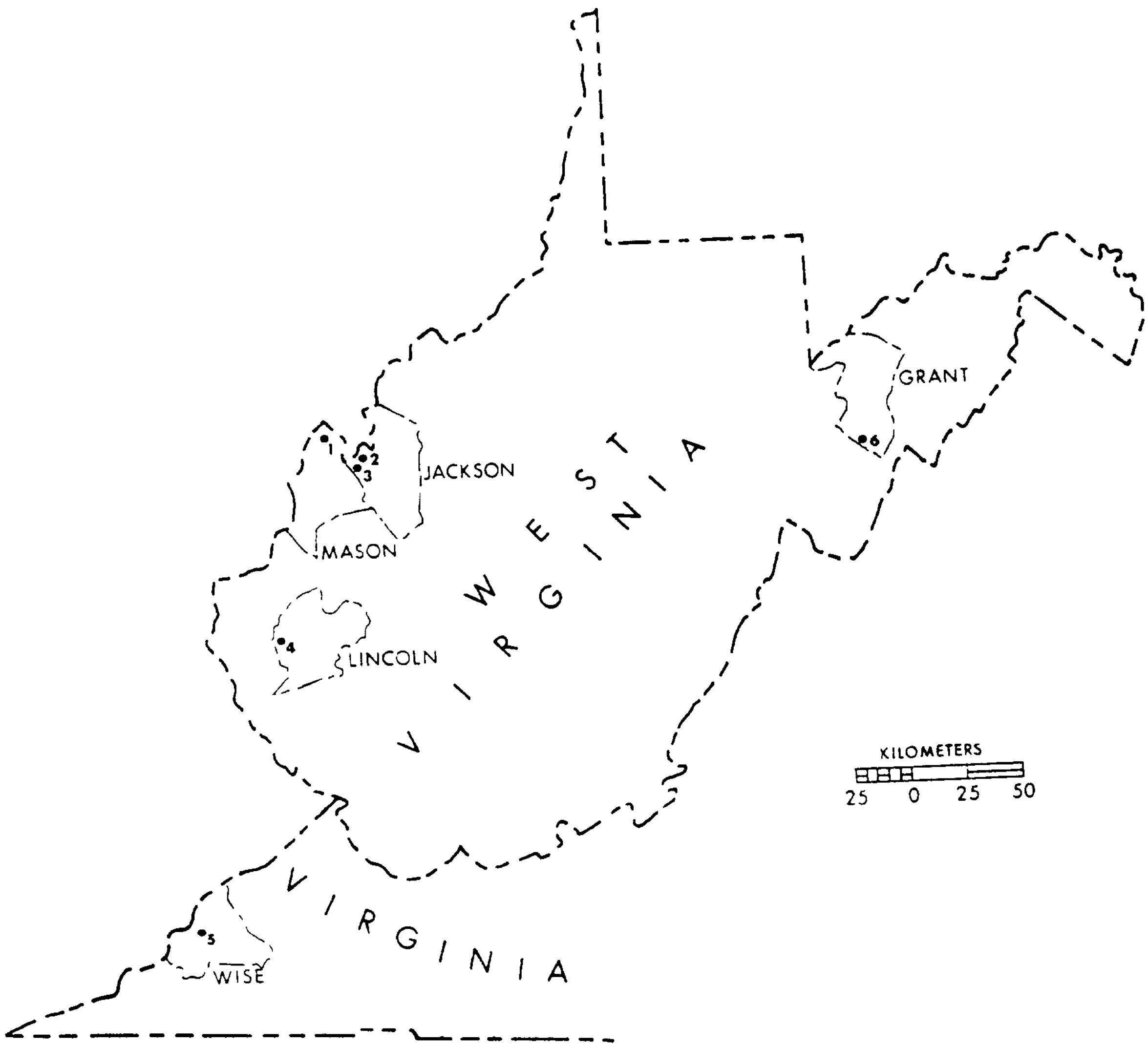


Figure 1. Location map of Devonian Shale cores and outcrops which served as sample sources for this study: 1) cored well - Mas 146, 2) cored well - Jac 1371, 3) cored well - Jac 1369, 4) cored well - Linc 1637, 5) cored well - Wise 253, 6) Devonian outcrops along Route 28.

Six distinct lithotypes are defined: (1) Thinly-laminated shale (Figure 2); (2) Lenticularly-laminated shale (Figure 3); (3) Sharply banded shale (Figure 4); (4) Non-banded shale (Figure 5); Siltstone (Figure 6) and Concretions (Figure 7).

Thinly-laminated shale is characterized by laminae, usually less than 2 mm in thickness which arise from alternate layering of light and dark shales, silt and/or pyritic matter. Most laminae are continuous across the slab with sharp contacts producing a highly ordered linear fabric. Bioturbation is lacking. Silt occurs as dispersed grains, as well-defined laminae, and as linear wisps which are often only a single grain in thickness. Thinly-laminated shale contains the highest organic content of the lithotypes.

Lenticularly-laminated shales possess a linear fabric notably less dense than that of the thinly-laminated lithotype. Laminae are usually less than 5 mm thick and consist mainly of light and dark colored shale. Laminae boundaries may be diffuse, and many laminae are discontinuous alignments of lenticles. Disruption of laminae by burrowing is not uncommon. Pyritic matter is concentrated in some laminae, but also occurs as nodular or wiry forms which are often not oriented along bedding planes to produce a sharp linear fabric element. Organic content varies from high to low.

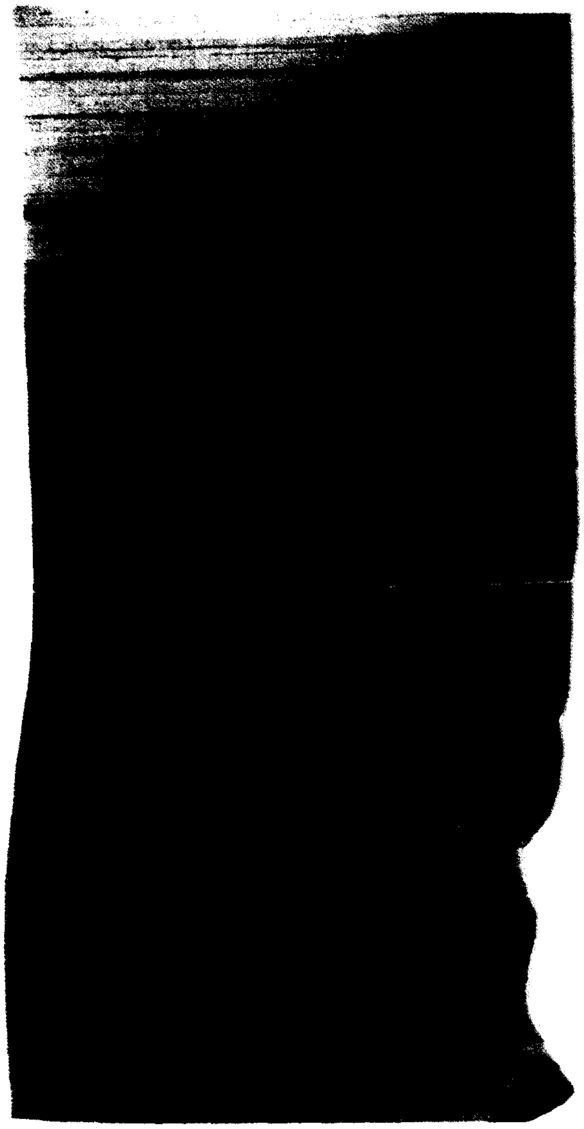
Sharply-banded shale is characterized by alternating light and dark bands each of which is usually greater than 1 cm thick. Bands may have internal structures such as laminae and burrows. The bedding planes defining the contacts between bands are usually sharply defined. Pyritic materials are usually arranged as linear fabric elements. The most common forms of pyrite in this shale type are spherical bodies which consist of framboids, spherical aggregates of framboids which are perhaps pyritized pellets, and pyritized algal spores.

Non-banded shales represent the most random arrangement of fabric elements. Bands or laminae are either originally absent or are so disrupted by bioturbation that only mottling is apparent. In some instances, vestiges of an original laminated fabric are visible. Pyritic matter and silt are uniformly disseminated through the rock and do not concentrate to produce a linear fabric.

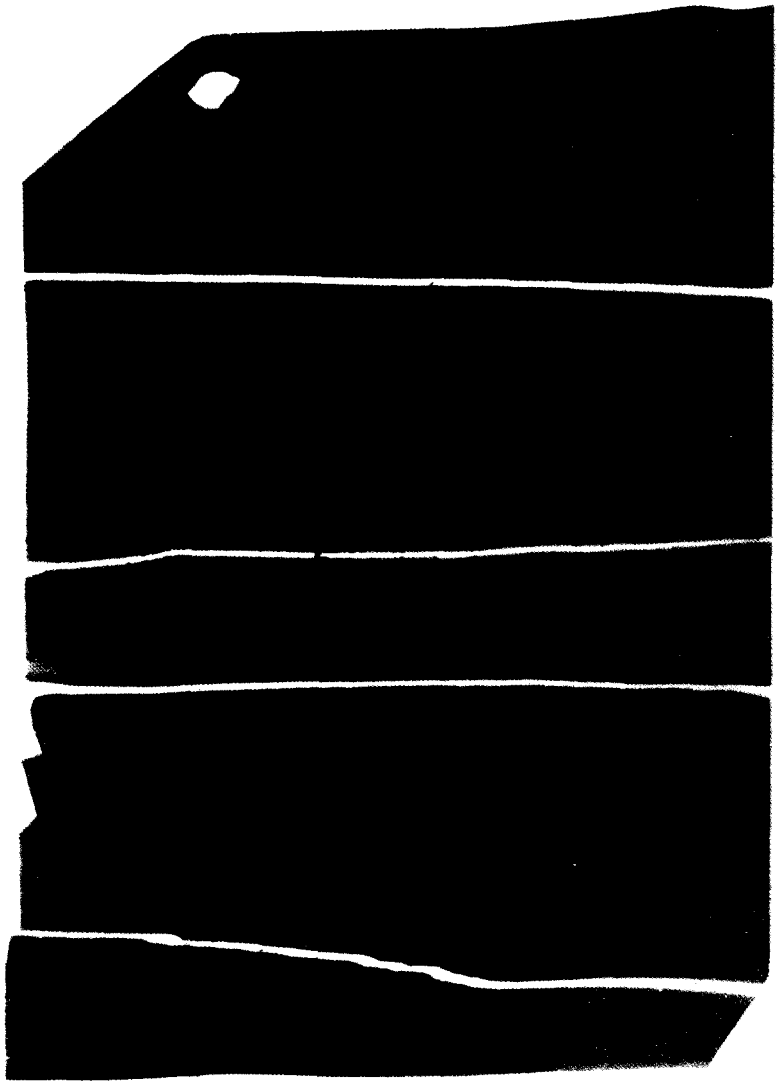
Two non-shale lithotypes, siltstones and concretions are present in minor amounts. Most siltstones are cross bedded, but some are massive except for grading. Concretions exhibit a wide variety of morphologies and internal structures.

Examples of these shale lithotypes, shown in the plates, were selected from actual representative variations present in each lithotype and thus the plates are not simply a compilation of the "best" examples.

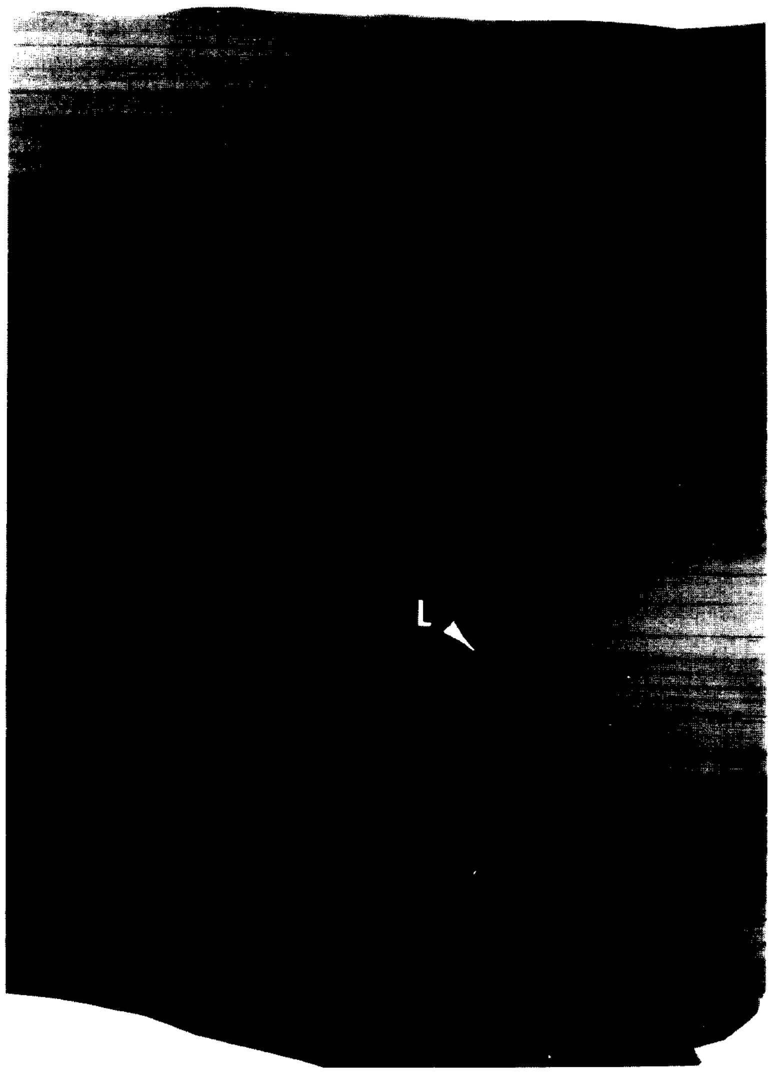
FIGURE 2. THINLY-LAMINATED FABRICS FROM UPPER DEVONIAN SHALES



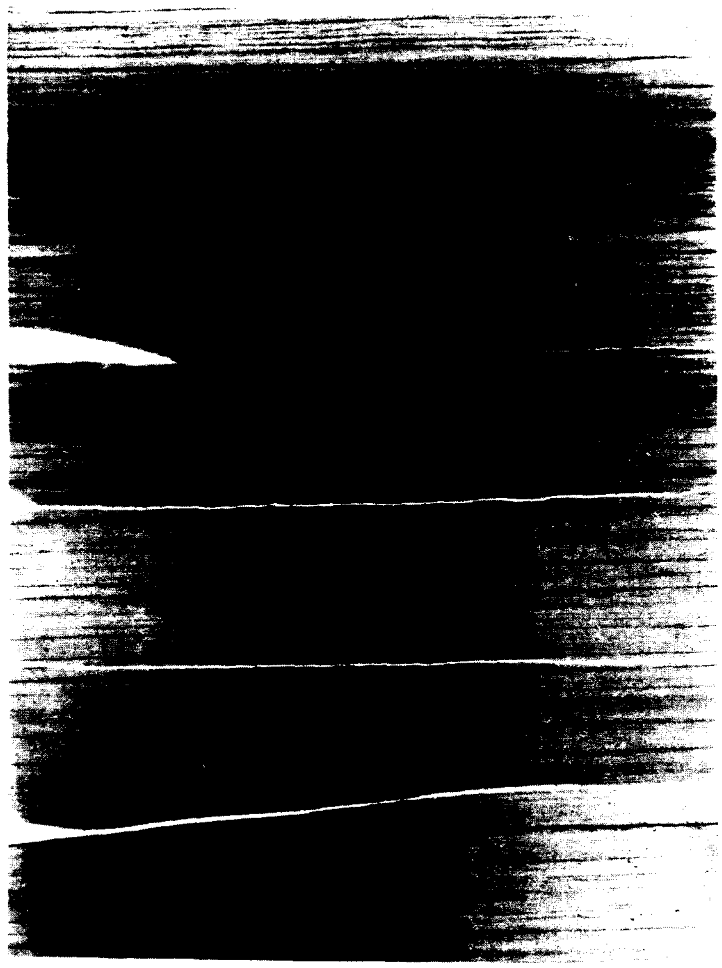
2A - Thinly-laminated shale in Rhinestreet Member of West Falls Formation. Virtually all laminae are continuous across the slab with sharp contacts producing a highly-ordered linear fabric. Differences in the amounts of clay, quartz, organic matter, and pyrite produce the radiographic tonal differences between laminae. Pyritic-rich laminae are revealed in darkest tones. The laminae show compaction around pyrite nodule (P). From Linc. 1637 at depth 4027.



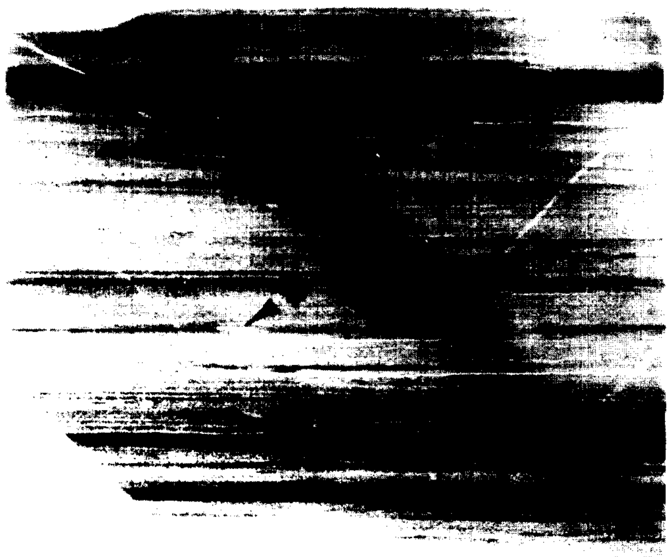
2B - Thinly-laminated shale in lower part of Huron Member. Most laminae are continuous and sharp; evidence of bioturbation is absent. Some laminae (L) pinch and swell and exhibit discontinuities probably caused by local variations in sediment transport-capacity of currents. Micro-cross lamination (C) indicates current activity. A 5mm-thick clay-rich laminae contains large pyritic framboidal aggregates (F). From Linc. 1637 at depth 3411.



2C - Thinly-laminated shale in Rhinestreet Member of West Falls Formation. Highly-ordered linear fabric is still present but laminae (L) are somewhat more discontinuous than in the two previous examples. The lack of visible evidence of burrowing suggests that the lack of continuity is a primary depositional feature perhaps controlled by current capacity and rate of sediment supply. From Linc. 1637 at depth 3991.5

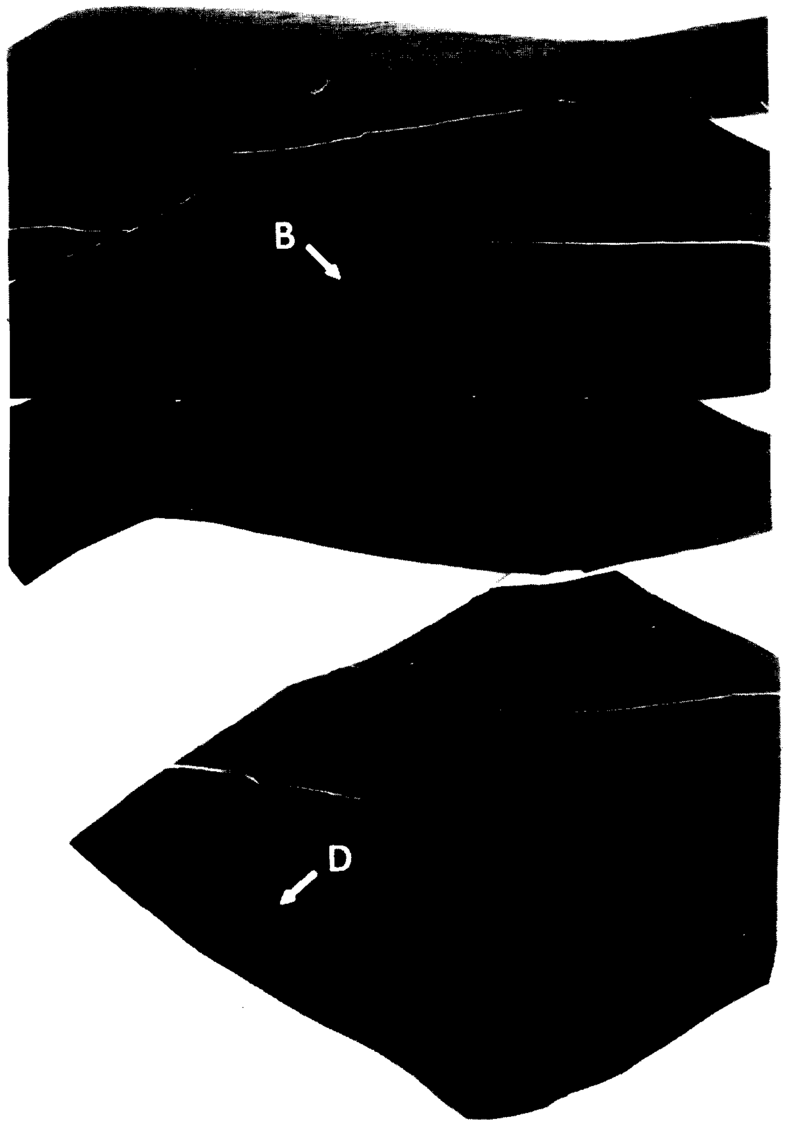


2D - Thinly-laminated shale in lower part of the Huron Member. Continuous nature of the laminae is dominant, but significant amount of discontinuity is present. Contacts between laminae are more diffuse (compare with 2A-2C). Structures such as at (B) may indicate traces of benthonic organisms at the sediment surface. Sand-sized pyritic bodies begin to show random (P) distribution as opposed to the alignment shown in the previous figures. From Linc. 1637 at depth 3549.

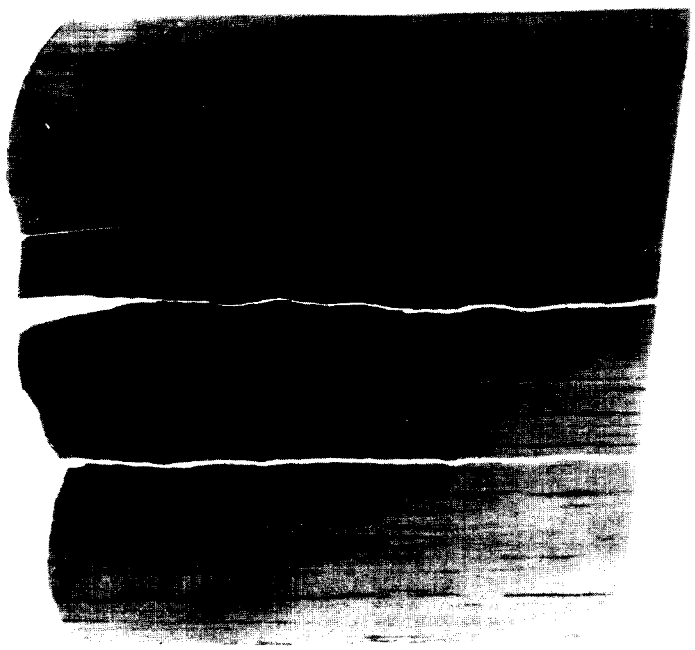


2E - Thinly laminated shale from Three Lick Bed. Linear fabric as defined by thin laminae is yet visible but many of the laminae now possess diffuse boundaries and undulatory contacts. Sand-sized pyrite (dark bodies) is dispersed through the rock or concentrated into broad bands. Horizontal burrowing such as shown at (B) may have been a factor in decreasing the lateral fabric continuity in this sample. Further development of diffuse contacts and discontinuity would produce a fabric classified into the lenticularly-laminated shale type (see Figure 3). From Wise 253 at depth 4903.4.

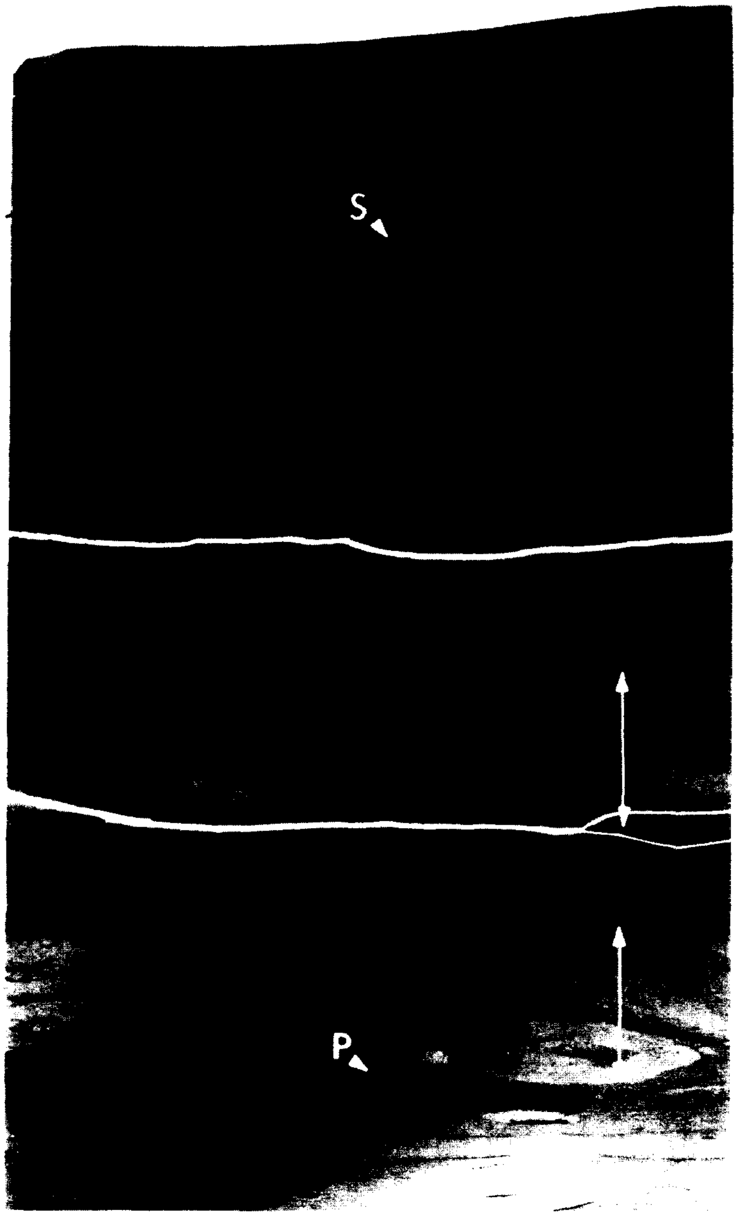
FIGURE 3. LENTICULARLY-LAMINATED FABRICS FROM UPPER DEVONIAN SHALES



3A - Lenticularly-laminated shale type in Rhinestreet Member of West Falls Formation. Linear fabric is notably less dense than that of the thinly-laminated lithotype (Figure 2). The linear fabric displayed by the pyritic-organic-rich laminae (dark tones) reveals diffuse boundaries and undulatory contacts (B). Disruption of laminae by burrowing as at (D) is not uncommon. Undulatory nature of some contacts is perhaps caused by heaving of sediment by burrowing organisms. From Linc. 1637 at depth 3938.5.



3B - Lenticularly laminated shale from lower portion of Huron Member. Linear fabric is obvious but all laminae exhibit discontinuity. Contacts are diffuse. Well-defined burrows are not common, but mottling and some fabric discontinuity suggests that small organisms may have been at times active at the sediment-water interface. From Wise 253 at depth 5444.6.

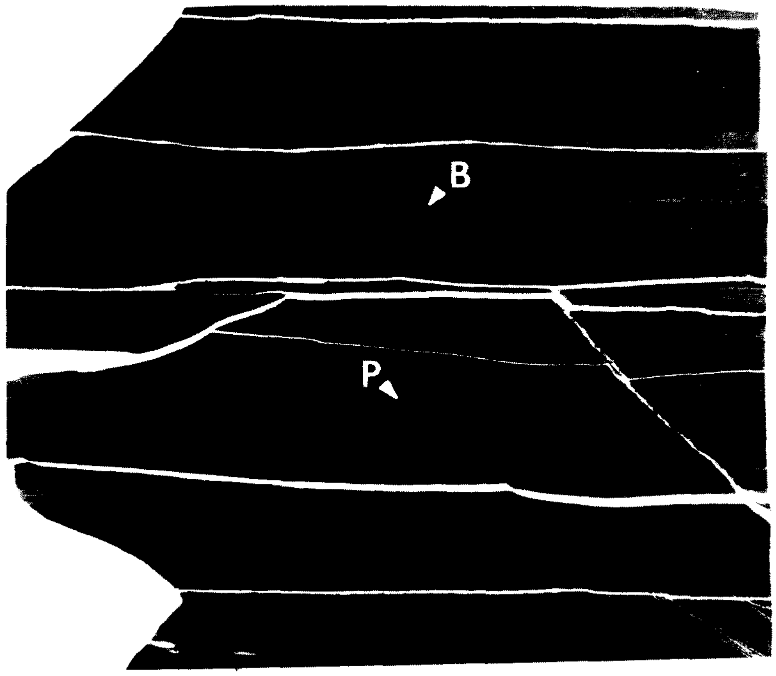


3C - Lenticularly-laminated shale type in lower part of Huron Member. Parts of this slab (intervals defined by white arrows) reveal well-defined burrow-mottling which severely disrupts linear fabric elements. Distribution of some pyrite (P) appears controlled by burrowing. Much pyrite is not aligned into linear fabric elements. Silt lenses about ½mm in thickness are visible as thin light tones in upper part of the slab (S). From Linc. 1637 at depth 3510.

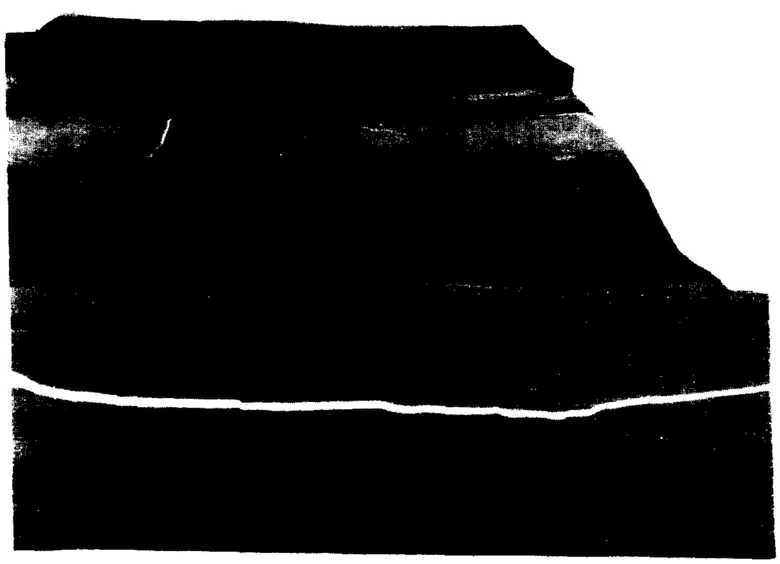
3D - Lenticularly-laminated shale from Java Formation showing more extensive bioturbation than previous examples. Linear fabric is still apparent, but continuity is low. Organic-pyritic-rich laminae (L) show severe disruption from burrowing. The large pyritic bodies (P) may be concretionary burrow fillings. From Linc. 1637 at depth 3671 .

3E - Lenticularly-laminated shale from lower part of Huron Member. Linear fabric is ill-defined after destruction by burrowing. Further removal of the remaining linear fabric elements would result in a non-banded lithotype. Wiry pyritic bodies (P) are probably fillings of synaeresis cracks, gas vesicles, and (or) small burrows. From Jac. 1369 at depth 3784.

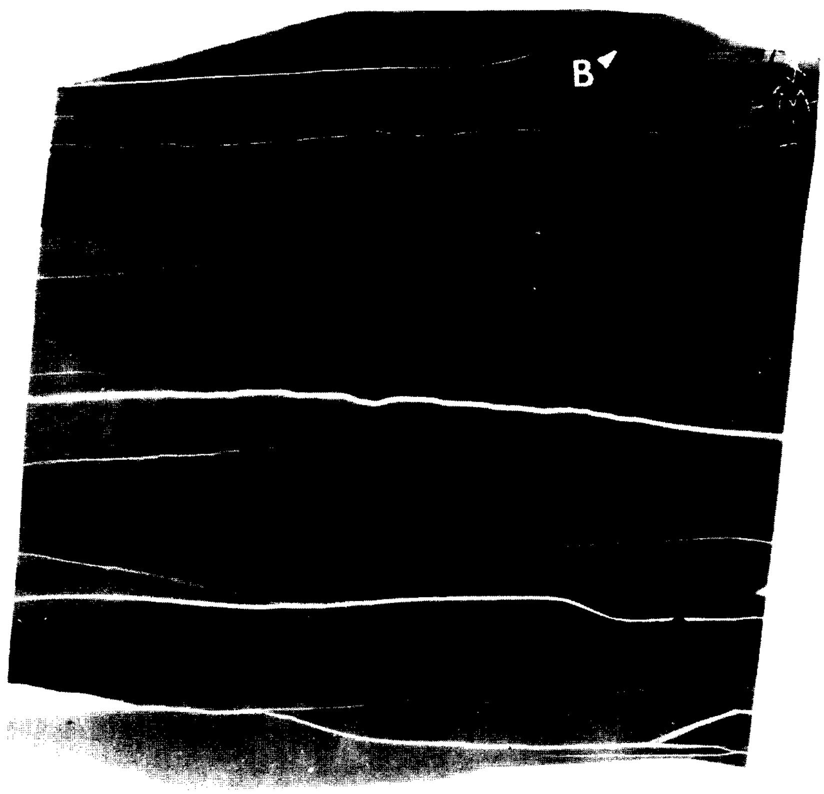
FIGURE 4. SHARPLY-BANDED FABRIC FROM UPPER DEVONIAN SHALES



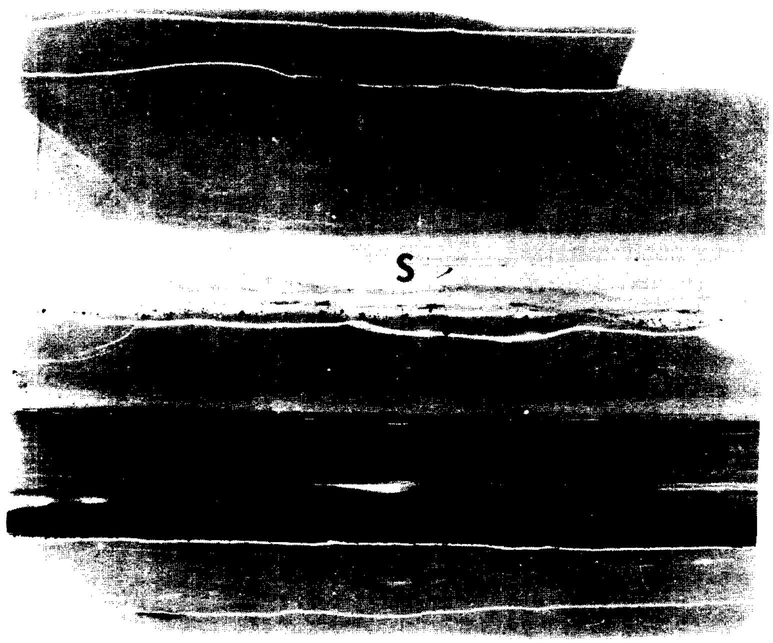
4A - Sharply-banded shale from undifferentiated shale above the Huron Member. This fabric is defined by the wide bands of alternating light and dark shale.A large portion of the pyritic matter consists of spheroidal particles (P) oriented along bedding planes to produce a linear fabric element. Some burrows (B) are present. The bands exceed 2mm in width and exhibit sharp contacts. From Linc. 1637 at depth 2899.



4B - Sharply-banded shale in undifferentiated shales above the Huron Member. Bioturbation has been extensive and the sharp nature of the contacts has been somewhat destroyed. However, the characteristic light and dark bands are yet recognizable.From Linc. 1637 at depth 2880.

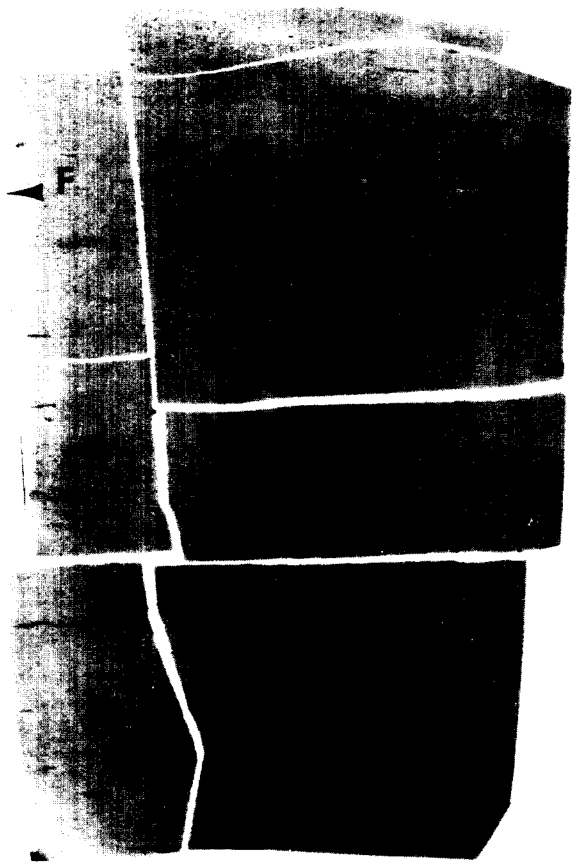


4C - Sharply-banded shale from lower part of Huron Member. Bands with little internal structure are dominant although the upper band contains some thinly-laminated fabric. In addition to spheroidal pyritic particles, pyritic matter in burrow fillings is abundant. Spheroidal bodies and burrow-fillings in some places coalesce to form solid bands. Some compactional deformation is exhibited around some filled burrows as at (B). From Jac. 1369 at depth 3497.

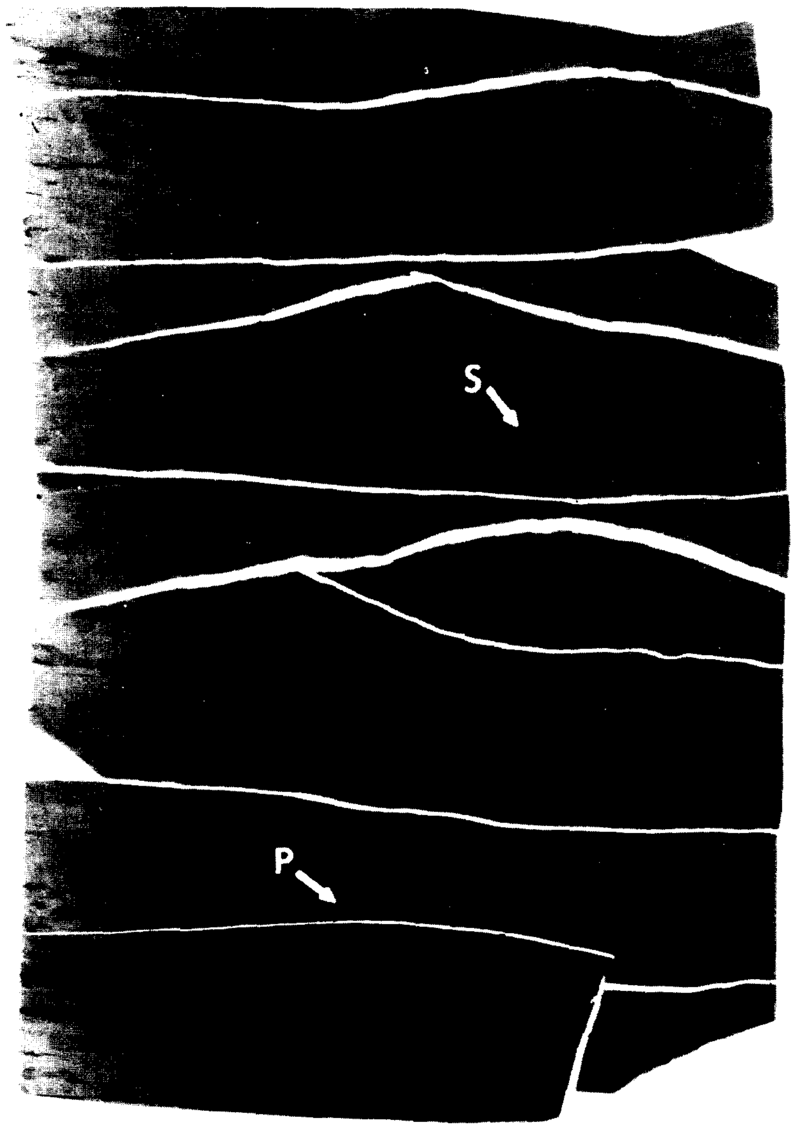


4D - Sharply-banded shale from lower part of Huron Member. In this slab, a siltstone (S) is interbedded with light gray bands of shale. Lower part of siltstone exhibits some burrows, current features, and possibly some loading at base. Spheroidal bodies of pyrite are concentrated along the scour surface at the base of the siltstone band. Dark band at lower portion of slab is comprised of spheroidal pyritic matter at base and finer disseminated pyrite throughout. Some traces of lenticularly-laminated fabric are present above the dark heavily-pyritized band. From Jac 1369 at depth 3641.

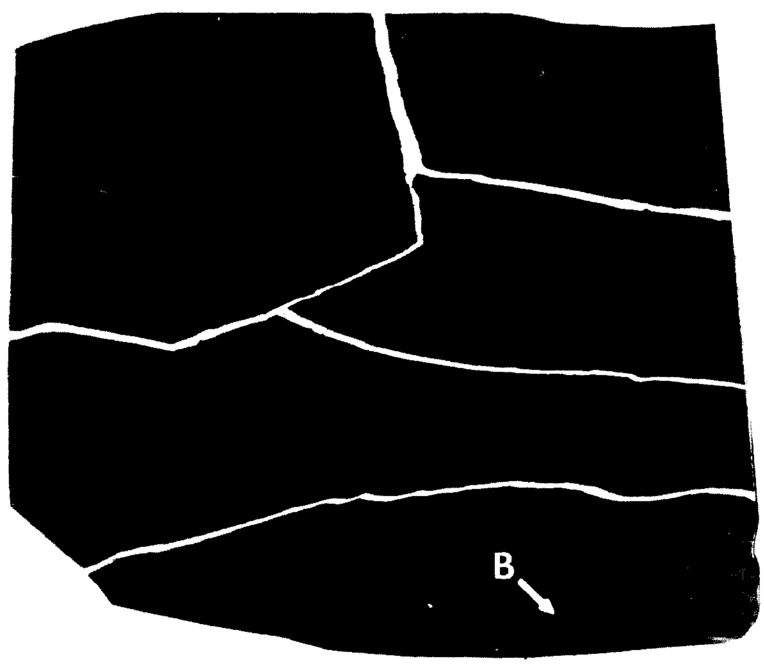
FIGURE 5. NON-BANDED FABRIC FROM UPPER DEVONIAN SHALES



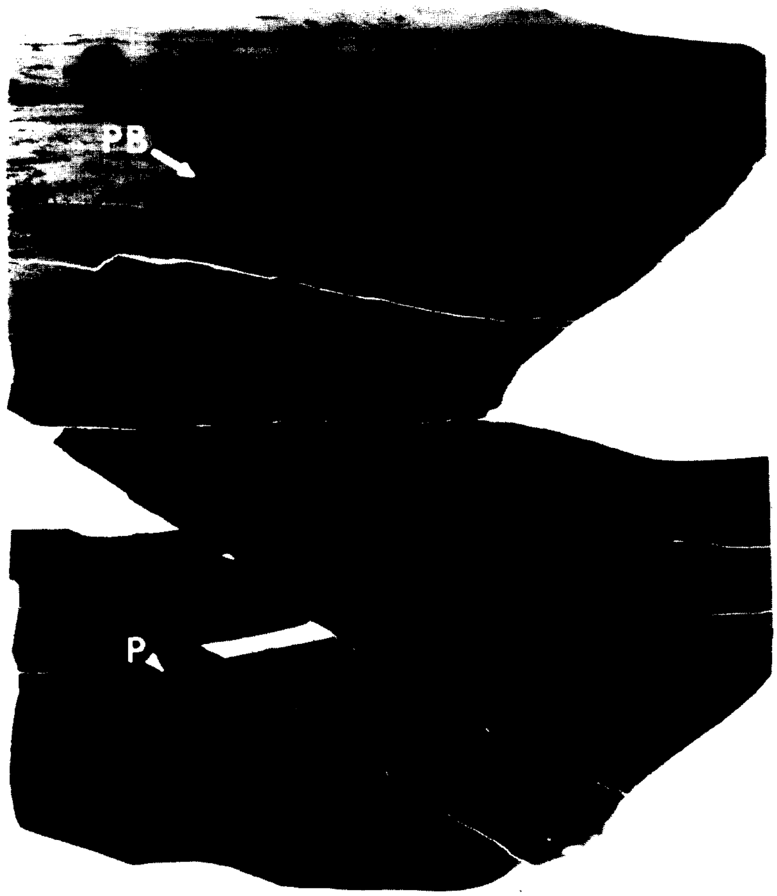
5A - Non-banded shale in lower part of Huron Member. Fabric exhibits lack of linear bedding-plane features; pyritic matter (dark tones) is not ordered into a linear fabric. Thin dark line on left-hand margin is a dolomite-mineralized fracture surface (F). From Jac 1369 at depth 3722.5.



5B - Non-banded shale in lower part of Huron Member. The sample lacks linear fabric except for a few organic-rich streaks with pyrite (S). Pyritic matter appears also to be present in small angular nodular bodies (P). These may represent filling of tiny cavities or burrows. From Jac. 1369 at depth 3754.

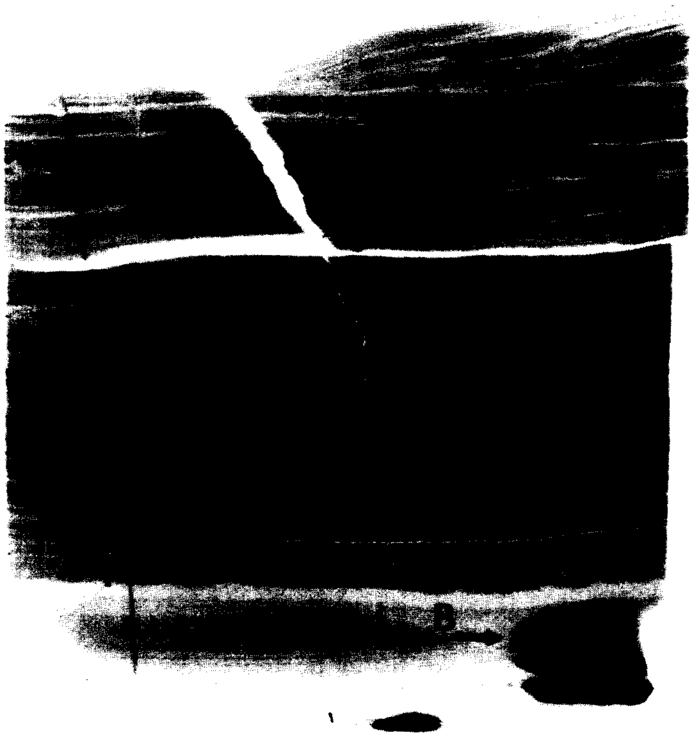


5C - Non-banded shale in lower part of Huron Member. This slab exhibits evidence of extensive bioturbation which disrupts what was apparently previously existing laminae or bands. Light tones as at (B) define burrows in darker-toned organic-pyritic shale. From Linc. 1637 at depth 3610.

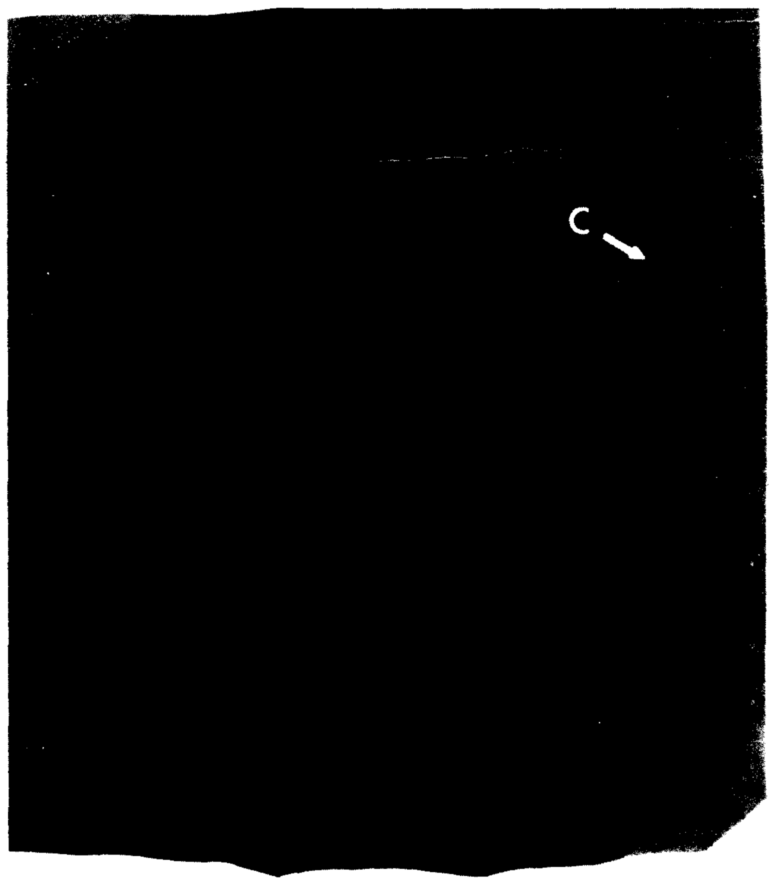


5D - Non-banded shale in upper part of Rhinestreet Member. This rock shows extensive pyritization of burrow-fillings (PB) and vestiges of pyritized (P) linear fabric elements. Prior to burrowing, the dominant fabric was probably lenticularly-laminated. From Linc. 1637 at depth 3883.

FIGURE 6. SILTSTONE LITHOTYPE



6A - Cross-bedded argillaceous siltstone from lower part of Huron Member. Erosive contact at base of cross-bedding overlies silty shale containing (B) pyritized burrows. Pyritic framboidal aggregates (P) are oriented along specific cross-laminations thus suggesting formation about the time of deposition. Specimen contains mineral filled fracture (F) in near-vertical orientation. From Wise 253 at depth 4965.

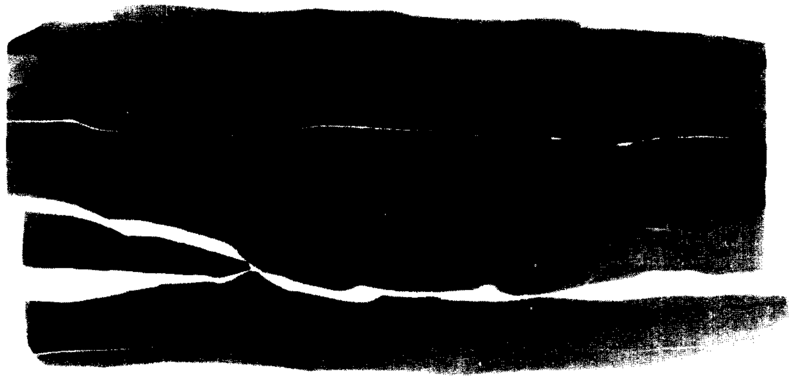


6B - Massive siltstone from lower part of Huron Member. Sample shows little internal structure except for grading of pyritized spores and framboids at base which suggests that perhaps a number of these pyritic bodies formed elsewhere and were transported in during time of siltstone deposition. Darker linear bodies are rip-up clasts of shale (C). This sample is unusual; most siltstones show cross-laminations. From Jac. 1369 at depth 3479.

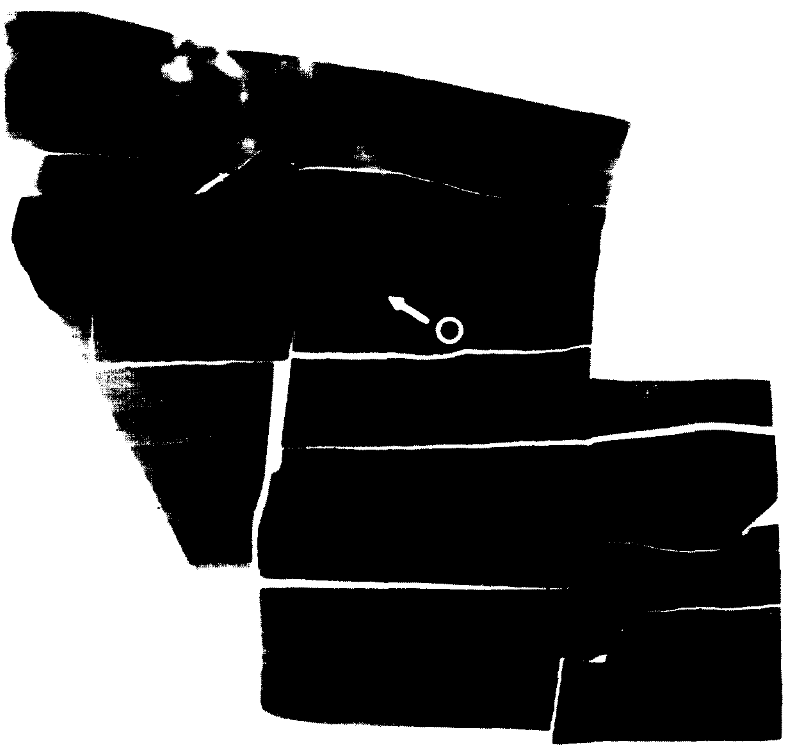
FIGURE 7. CONCRETIONS IN UPPER DEVONIAN SHALES

7A - Cone-in-cone structure in calcite concretionary zone in grey shale of upper-middle portion of Huron Member. Linc 1637 at depth 3238.4.

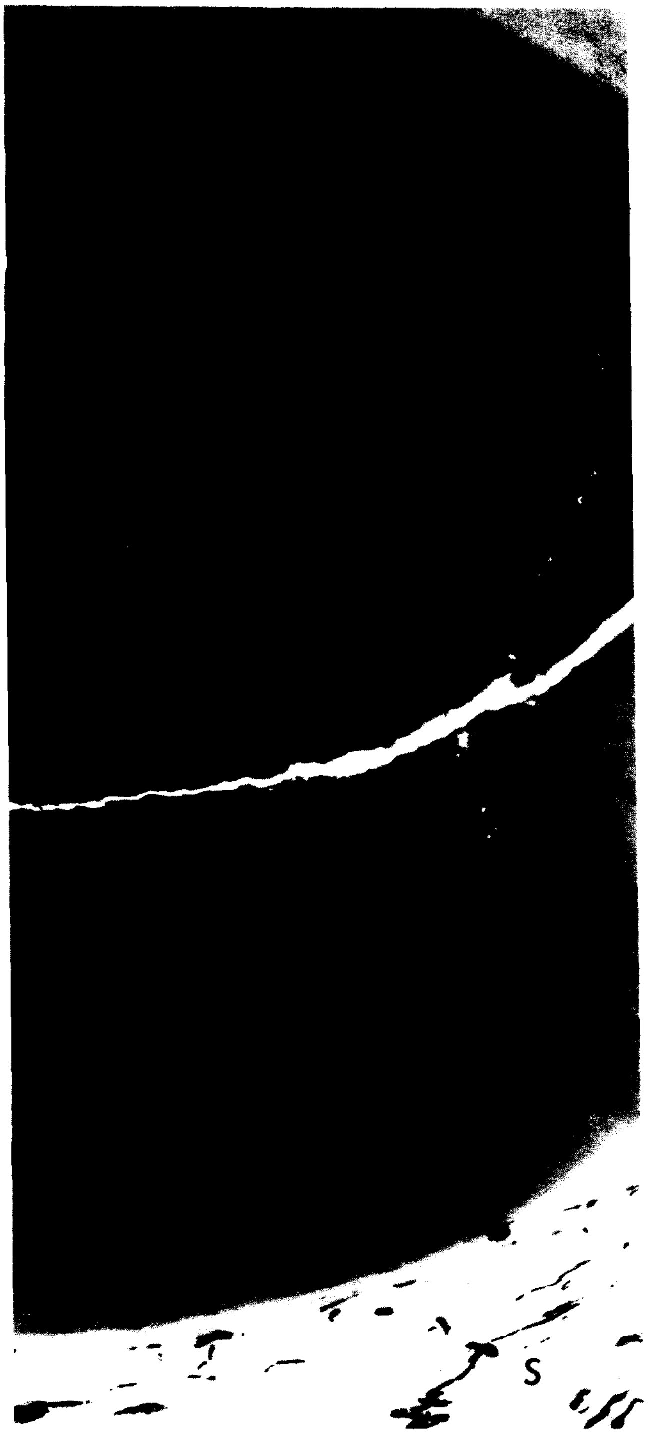
7B - Concretionary aggregate of euhedral barite crystals developed in non-banded shale in Angola Shale Member of the West Falls Formation. The barite crystals apparently formed early in the unconsolidated sediment as evidenced by compaction of laminae around the aggregate. Linc 1637 at depth 3789.



7C - Lenticular siderite concretions in Rhinestreet Member of West Falls Formation. Concretions pinch and swell and generally possess a homogeneous internal structure. They are considered early diagenetic features. Linc 1637 at depth 3914.2.



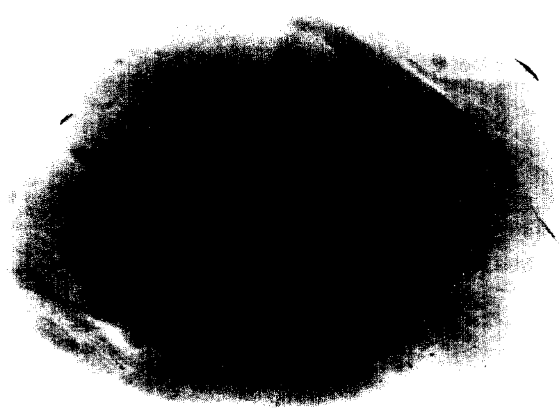
7D - Zoned concretion in thinly-laminated organic rich shale of Rhinestreet Member of West Falls Formation. Outer zone of concretion (O) is pyrite with central core being composed of calcite that has filled original epidiagenetic pore space and later, to some degree, replaced the original quartz (deduced from thin-section studies) rich matrix. Note greater thickness of laminae in concretion reflecting preservation of pre-compaction fabric. Linc 1637 at depth 3962.



7E - Septarian concretion collected from Rhinestreet Member of West Falls Formation. Concretion is predominantly calcite with septarian cracks containing later generation of calcite. Note compacted shale (S) in concentric layers around concretion at bottom. Mas 146 at depth 3374.

7F - Septarian concretion collected from Marcellus Fm. along Route 28, Grant Co., West Virginia. Sideritic concretion contains septarian cracks filled with barite.

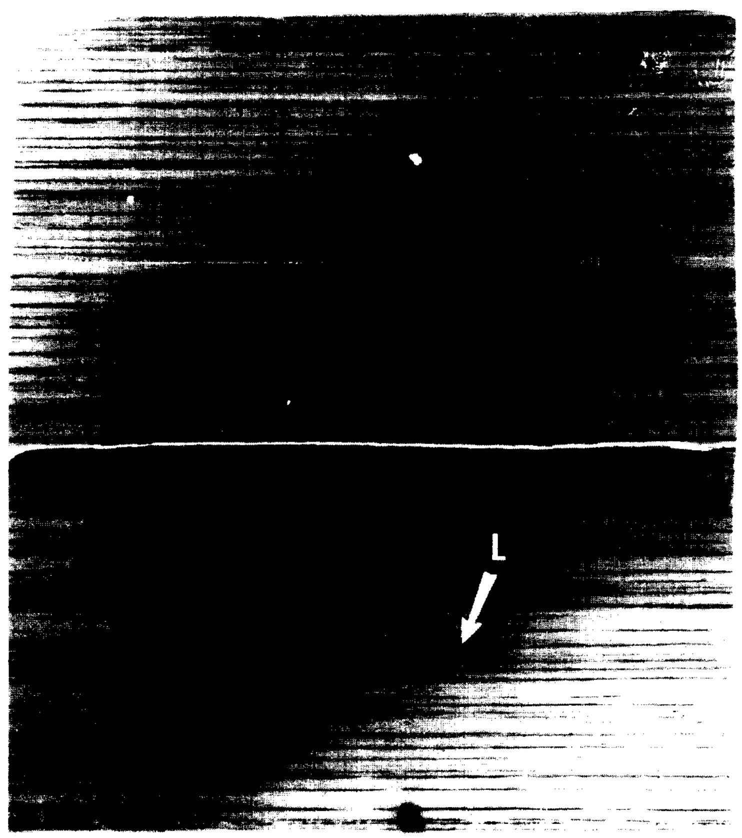
7G - Concretion collected from Marcellus Fm., 13 meters higher in section than previous sample, is composed principally of calcite, with multiple sites of growth origin. Some septarian cracks filled with calcite are partially zoned by concentric fractures.



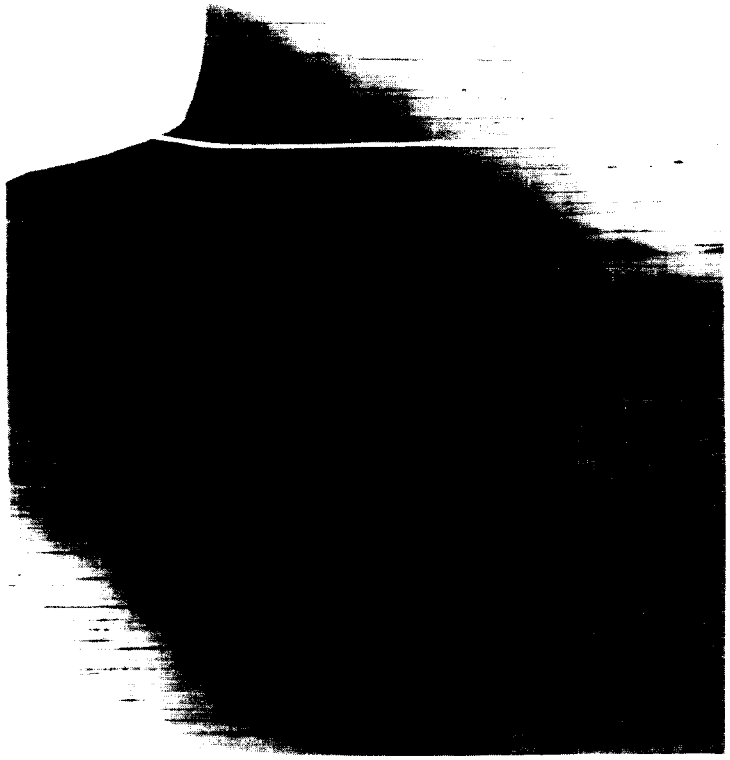
7H - Concretion collected from Marcellus Fm., 2 meters higher in section than previous sample. Bioturbation is preserved in calcitic concretion including one burrow (upper-left) which still contains its occupant (F).

FIGURE 8. SERIES OF RADIOGRAPHS SHOWING TRANSITIONAL NATURE OF SHALES FROM HIGHLY ORDERED TO HIGHLY RANDOM FABRIC CHARACTER.

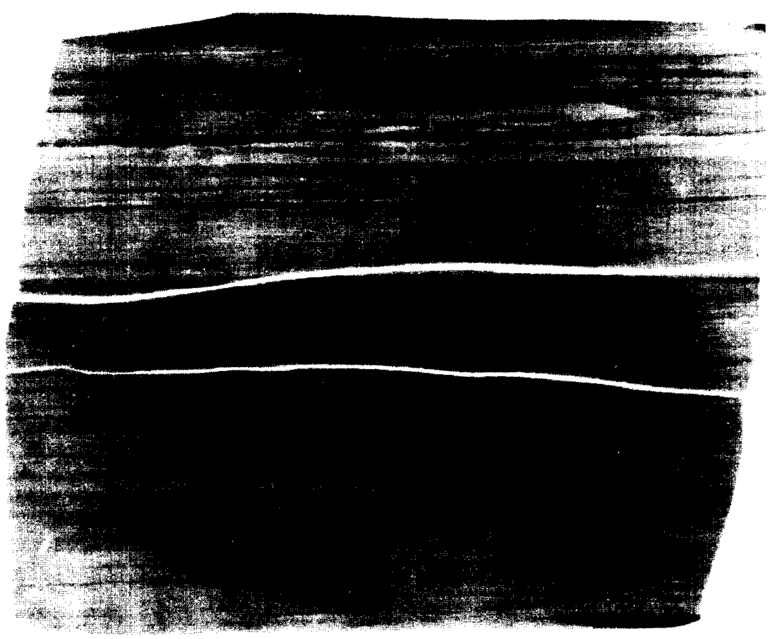
8A - Thinly-laminated shale exhibiting sharp contacts and high density of laminae. Such fabric represents the most highly-ordered fabric and the best developed lateral continuity. From Jac. 1369 at depth 3411.2.



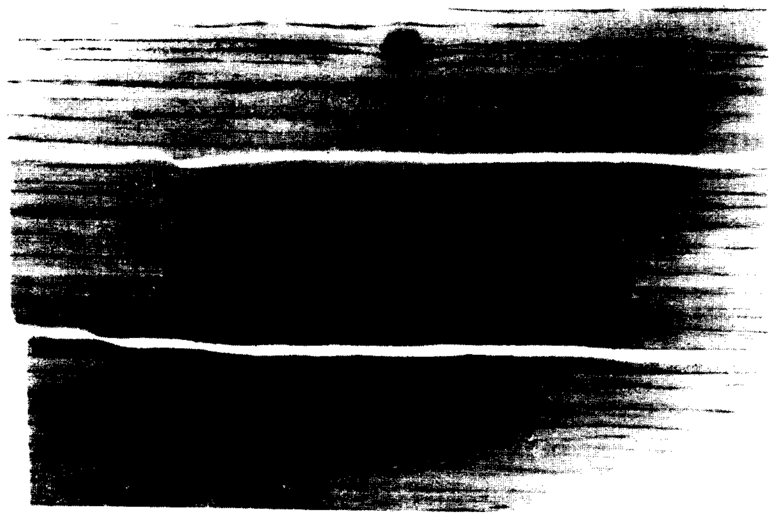
8B - Thinly-laminated shale similar to 8A but now containing some discontinuous lenticular laminae (L) with diffuse contacts. Most pyritic material is aligned into thin, dark laminae but some nodules are present. From Jac. 1369 at depth 3699.5.



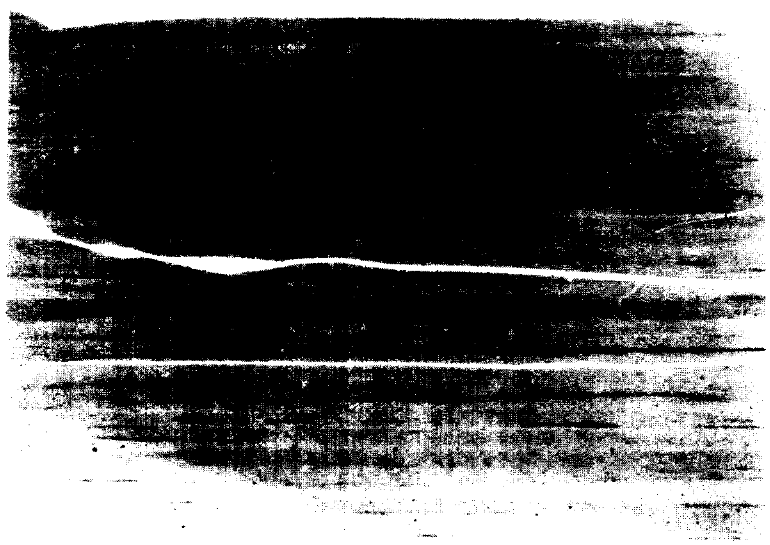
8C - Thinly-laminated shale similar to 8B but with many more lenticular laminae with diffuse contacts. Most laminae are thin with sharp boundaries and pyritic matter is concentrated into sharp linear fabric elements. From Linc. 1637 at depth 3447.



8D - Lenticularly-laminated shale which consists mainly of laminae with diffuse boundaries. Some characteristics of the thinly-laminated shale type are yet present in subordinate amounts. Burrows (B) are becoming more apparent. From Jac 1369 at depth 3676.

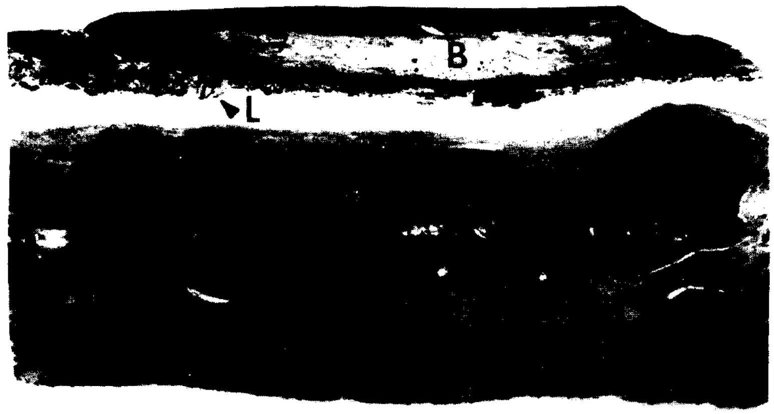


8E Lenticularly-laminated shale similar to 8D but virtually all laminae are discontinuous with diffuse boundaries. Discontinuous and undulatory nature of some laminae (L) are caused by bioturbation but most of the discontinuity is a primary sedimentary characteristic. From Jac. 1369 at depth 3795.

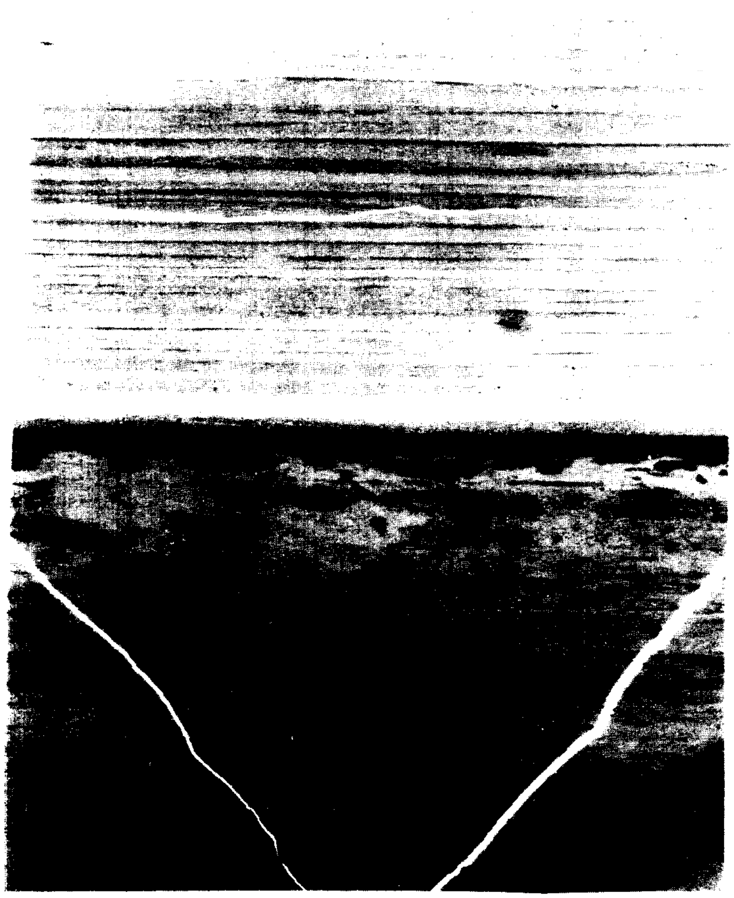


8F Lenticularly-laminated shale similar to 8E but laminae show a greater degree of discontinuity which increases the randomness of the overall fabric of the rock. Many sand-sized pyritic bodies are scattered through the rock matrix, although some (P) is still aligned along bedding planes. From Jac.1369 at depth 3782.

8G - Non-banded shale type with vestiges of lenticular-laminae yet present. Evidence of burrow-mottling is seen in upper portions of the slab. Ordering of fabric defined by linear bedding plane elements is very low. From Linc. 1637 at depth 3618. Transition series from 8A through 8G has been characterized by decreasing lateral continuity, decreasing density of laminae per unit thickness of rock, decreasing sharpness of laminae boundaries, and increasing evidence of bioturbation.

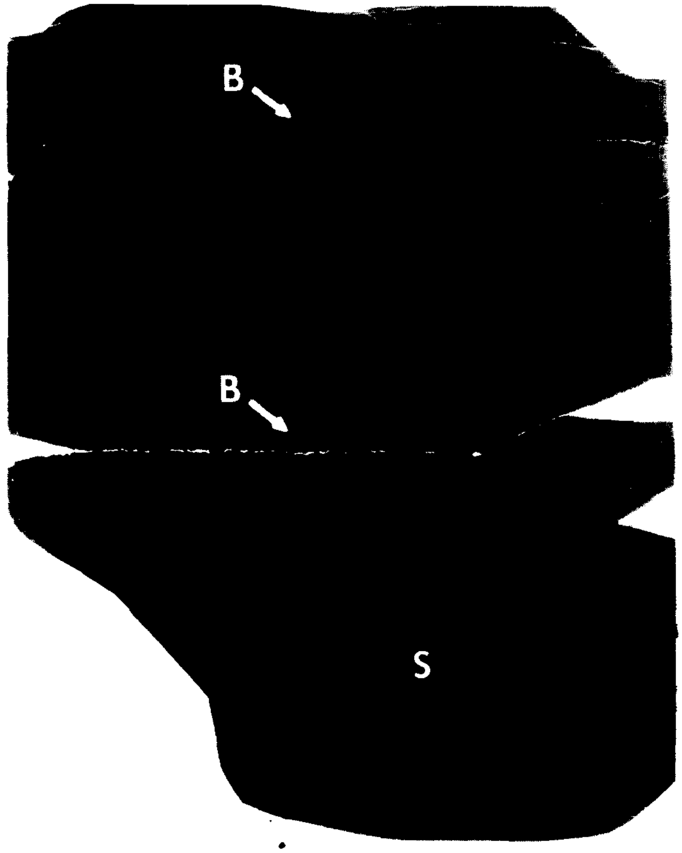


9A - Unconformable contact between Middle Devonian Onondaga Limestone and Upper Devonian West Falls Formation. Contact is marked by a thin zone (L) rich in quartz sand, limestone fragments, and conodonts. Lentoidal bentonite bodies (B) are also present. Linc 1637 at depth 4030.8.

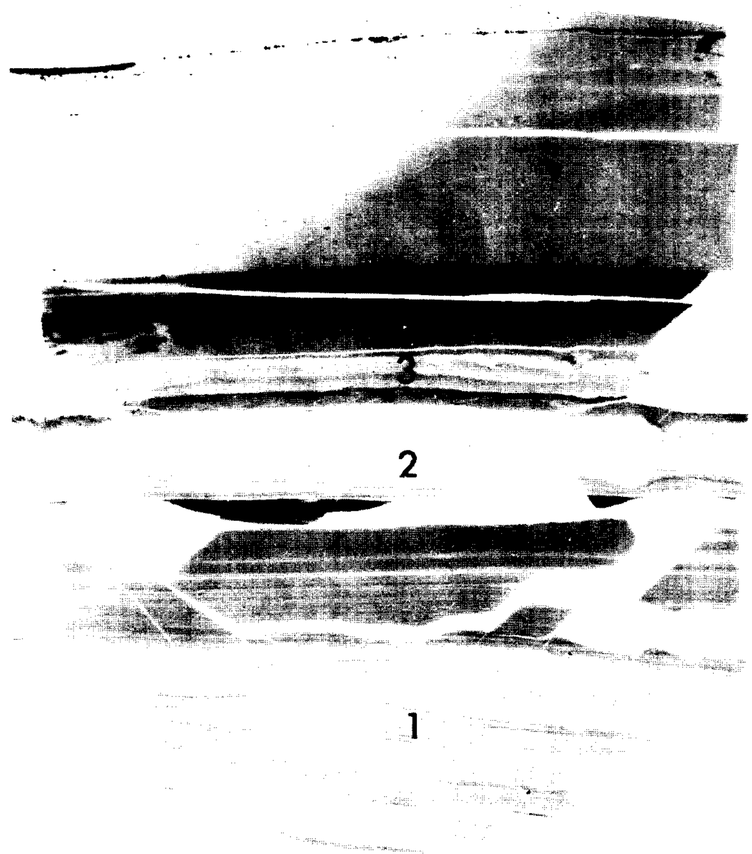


9B - Contact between thinly-laminated and non-banded shale lithotypes in lower portion of Huron Member. Contact is sharp implying a rapid change in depositional environment. Concentration of pyrite in non-banded shale increases towards contact. Linc 1637 at depth 3583.

9C - Bed of non-banded shale enclosed by thinly-laminated shale in lower portion of Huron Member. Sharp contacts of non-banded shale bed are interpreted as indicating a rapid influx of sediment into an environment favorable to laminated shale formation. Jac 1369 at depth 3465.

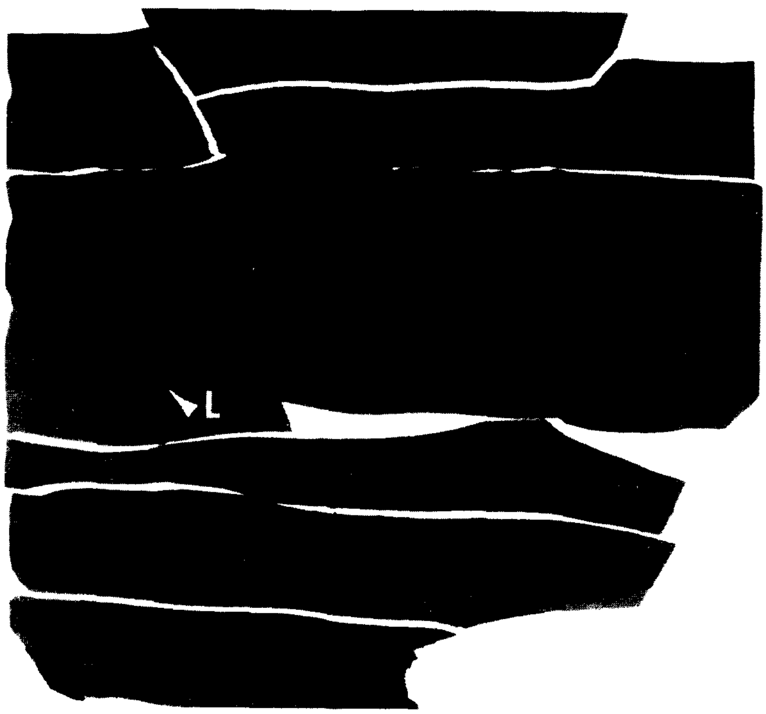


9D - Thin bands (B) of organic rich shale in non-banded grey shale of lower portion of Huron Member. Organic rich bands contain abundant pyritized spores. Lack of bioturbation in these thin bands and the enclosing shale may indicate rapid deposition. Lower, thick band (S) is a siderite concretion. Wise 253 at depth 5225.



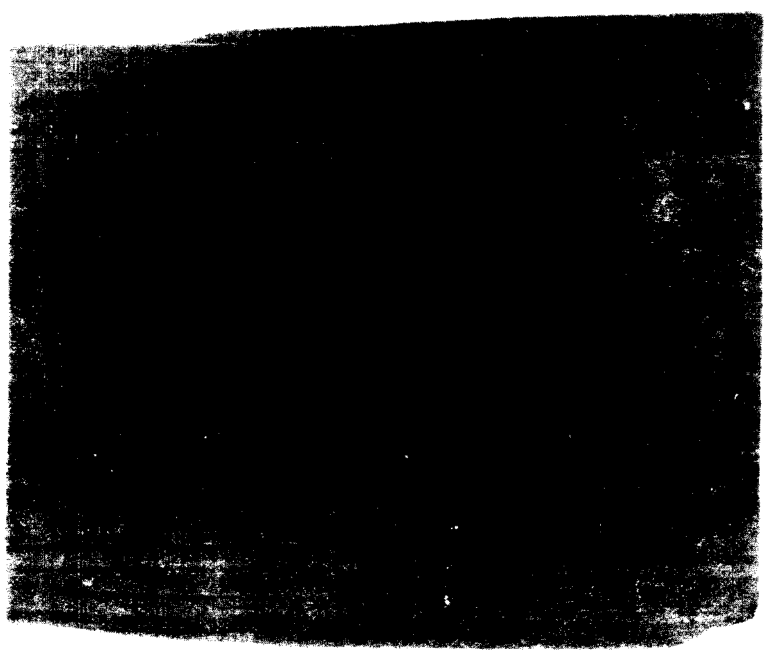
9E - Banded shale consisting of alternating sequence of siltstone and shale. Lower crossbedded siltstone (1) is overlain by thinly-laminated silty shale which is in turn overlain by siltstone (2) containing burrows. This siltstone is overlain by a thin shale band which is succeeded by another thin burrowed siltstone (3). Note distribution of pyrite (P) apparently controlled by burrowing at contact between organic rich and organic poor shale bands. Linc 1637 at depth 2765.

9F - Contact between siltstone and lenticularly-laminated shale in lower portion of Huron Member. Contact is sharp and probably erosional indicating that the shale was perhaps cohesive at time of siltstone deposition. Jab 1371 at depth 3255.



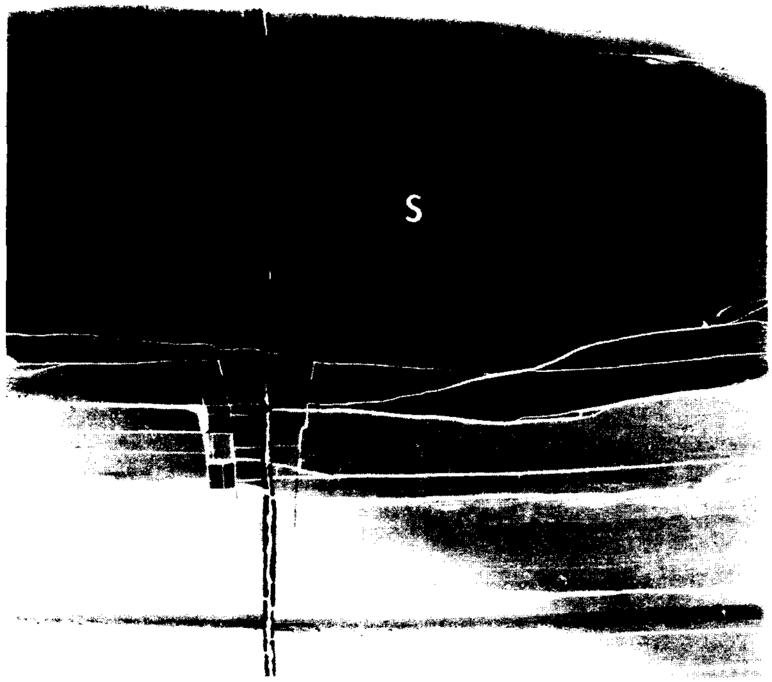
9G - Soft sediment deformation in banded shale of upper-middle portion of Huron Member. Well defined load casts (L) are developed at base of siltstone band. Primary laminae in siltstone loadings are generally undisturbed. Linc 1637 at depth 3377.

9H - Soft sediment deformation in banded shale of upper-middle portion of Huron Member. Flame structures (F) are developed at base of thin siltstone band. Linc 1637 at depth 3028.6.

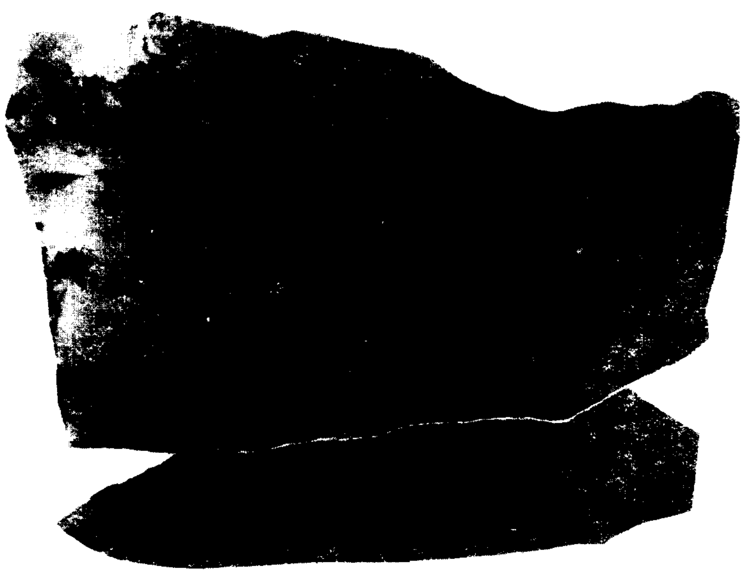


9I - Soft sediment deformation in argillaceous siltstone of upper-middle portion of Huron Member. Convolute laminae are bounded by planar laminae. Note general parallelism of fold axes. Linc 1637 at depth 3173.

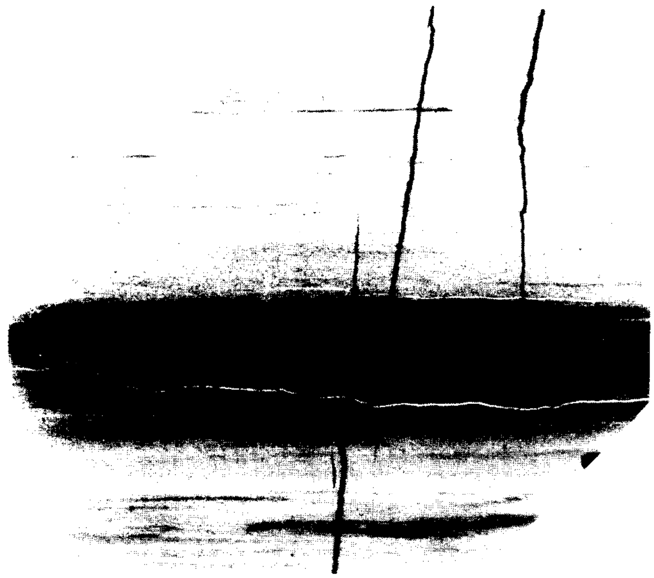
FIGURE 10. FRACTURES IN UPPER DEVONIAN SHALES



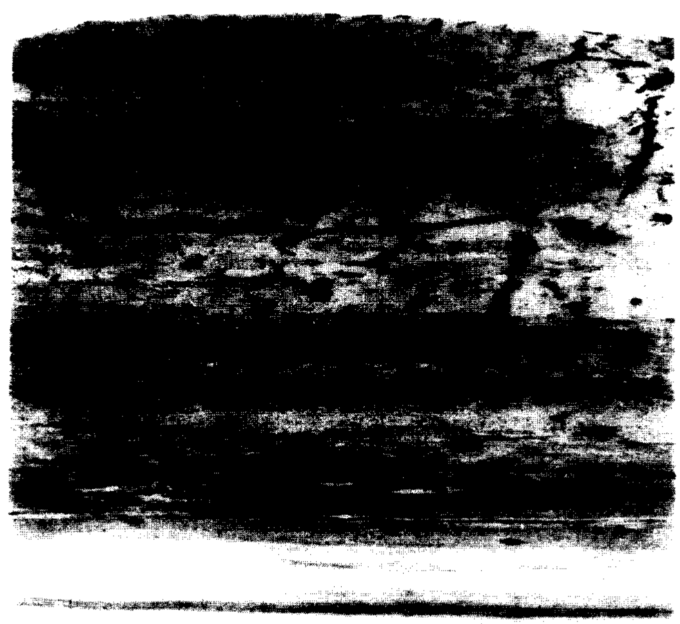
10A - Vertical carbonate-filled fracture in upper portion of Huron Member. Note splaying of fracture above and below large siderite concretion (S). Fracture changes from generally planar path in shale to undulatory pattern in concretion. Apparent voids in center of fracture are due to plucking. Linc 1637 at depth 3057.



10B - Fault breccia from Java Formation. Many pieces of the shale can be seen to have been rotated at least 90°. Breccia is tightly cemented by pyrite (P) which reduces permeability. No gas show is associated with this fracture as indicated by temperature log. Linc 1637 at depth 3757.

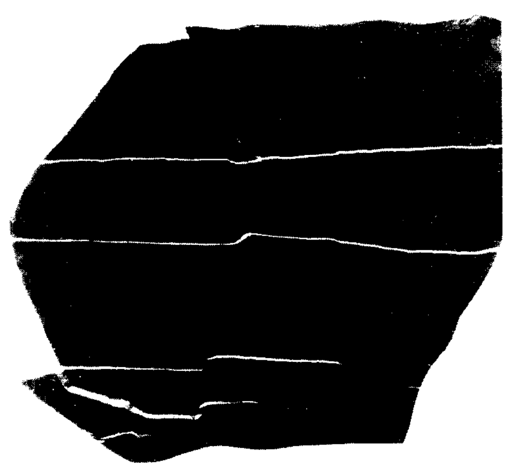


10C - Subvertical fractures in lenticularly-laminated shale of Three Lick Bed. Fractures are seen in thin section to be tightly cemented by dolomite and possess little intercrystalline porosity. Wise 253 at depth 4914.



10D - Pyrite filled synaeresis fractures (S) from Three Lick Bed. Fractures are developed in bioturbated non-banded shale. Wise 253 at depth 4925.

10E - Fractures associated with tight folding in Three Lick Bed. They are tightly mineralized by carbonates and sulfates. Wise 253 at depth 4930.



10F - Interpreted sediment slump structures from lower portion of Huron Member. Laminae in middle of sample are offset along plane which passes up into folded and finally unbroken laminae. Wise 253 at depth 5435.

VERTICAL PROFILE ANALYSIS

The shale lithotypes, which are easily defined on the basis of fabric elements, are almost certainly products of the depositional environment. Unfortunately, fabrics of marine shale and fine-grained muds have been studied to a lesser extent than those of carbonate and coarse clastic sediments. For the case of the vertical profile of the Linc 1637 well examined here, modern analyses of the lithotypes are scarce (Figure 11).

The association of thin siltstone with the sharply-banded shale type from the upper portion of the core is interpreted as prodelta deposits, part of the Catskill delta from the east (see Schwietering, 1977). These siltstones of the associated sharply-banded shale are interpreted as depositional pulses similar to those described by Van Straaten (1959) for the Rhone delta. Perhaps the thicker bands are indicative of rapid sedimentation.

The thinly-laminated lithotype is dominant in the lower part of the Huron Member and the lower Rhinestreet Member. The lower part of the Huron Member is the major gas producing interval in the Devonian shale sequence of West Virginia and was productive in this well. Thin laminae in fine-grained clastic rocks are not definitive of any particular environment; they are found in lacustrine deposits, on tidal flats, and in deep marine environments. Explanations of mode of formation are diverse, and include both setling from suspensions to form primary laminae and reworking after deposition by bottom currents to create laminated fabric (Reineck and Singh, 1975).

The accumulation of the Rhinestreet Member on top of the unconformity surface at the Onondaga Limestone in this well (see Duffield, 1978), leaves little doubt that the thinly-laminated lithotype can accumulate in a shallow marine environment. The abrupt transition from the light gray non-banded and lenticularly-laminated shales of the Java Formation to the dark thinly-laminated shales of the lower part of the Huron suggests a distinct change in environment of deposition in Lincoln County.

Data from McIver and Zielinski (1978) and Zielinski, Nance, Seabaugh, and Larson (1978) based on organic geochemistry and palynology indicates increasing amounts of terrestrially derived organic matter southward from Lincoln County, and increasing marine influence to the north and east. Thus streams from a low-relief land mass to the south and southeast could be designated as the sediment source of the lower Huron in Lincoln County. Frequent (annual ?) floods could have provided current mechanism for moving the fine-grained organic-rich detrital sediment into the shallow basin to settle on to a bottom made anoxic either by water stratification or by the sheer volume of organic matter being contributed from both the source area and from algal productivity in the upper water column. The laminae are interpreted as being produced by sedimentation from current-generated suspension clouds (see Reineck and Singh, p. 220-221) in the upper water columns and by subtidal currents which probably gently reworked the bottom sediments to produce some laminae of silt wisps and lenses. Further laminae were created by formation of early diagenetic pyrite at or very near to the

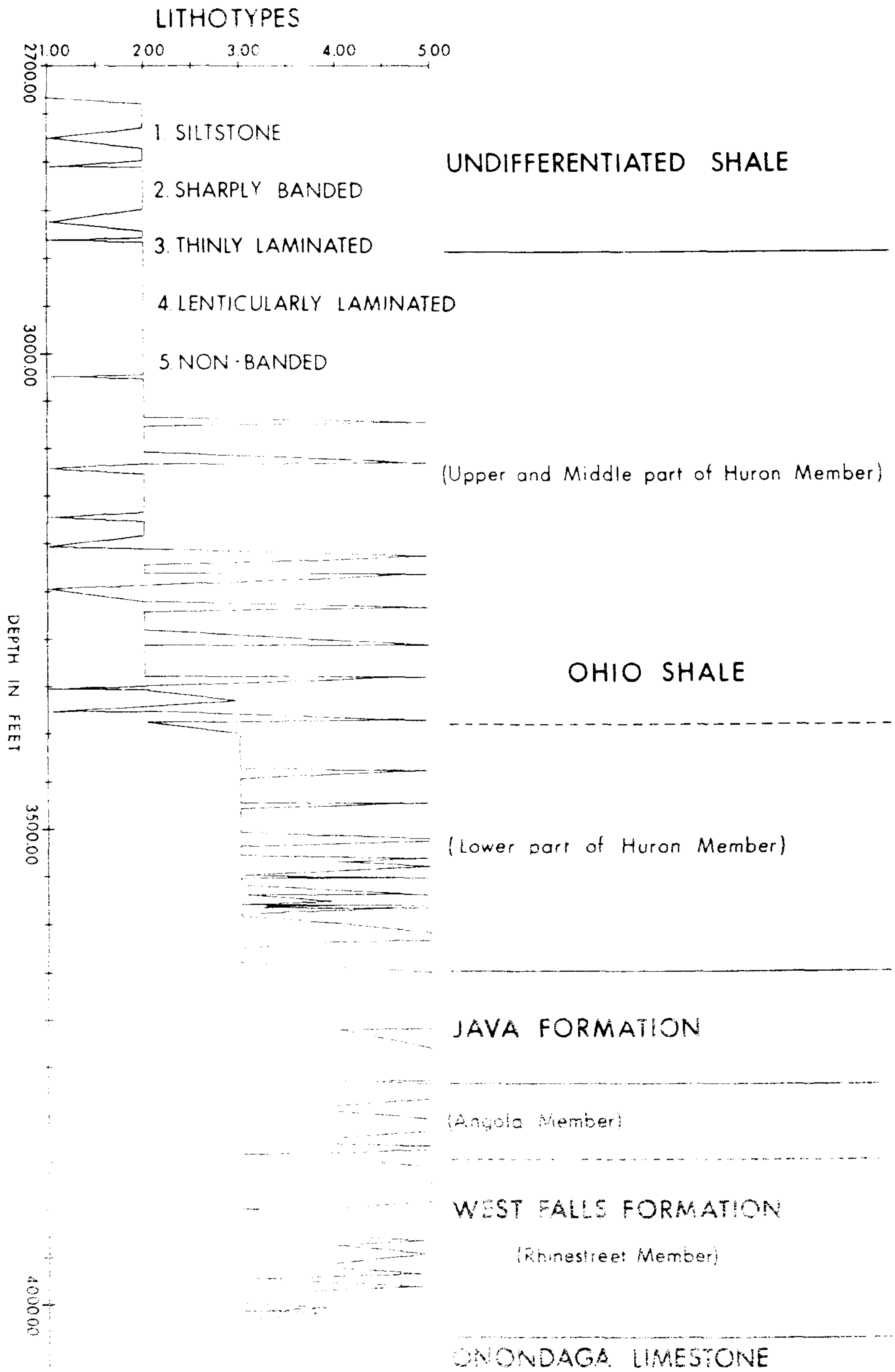


Fig. 11. Vertical distribution of shale lithotypes in stratigraphic profile of cored well Lin: [illegible].

sediment-water interface. Lack of scour features, non-disruption of linear fabric of pyrite, absence of rip-up clasts, scarcity of burrowing organisms and high content of organic matter indicate general persistence of low-energy anoxic bottom conditions. These conditions were frequently disturbed by turbidites as evidenced by some lenticularly-laminated light shales and siltstone beds found within the dark thinly-laminated shales. There is no evidence to indicate that these shales were ever deposited above wave-base.

Gas production from the lower portion of the Huron Member in southwestern West Virginia is explained by the dominance there of the thinly-laminated lithotype which promotes lateral continuity of the meager porosity present (Nuhfer and Vinopal, 1979). The associated high organic content probably increases the methane-sorption capacity of the shales so that this lithotype can store more gas per given volume of rock that would be indicated from porosity measurements alone (Schettler, 1978).

Non-banded and lenticularly laminated shales contain much finer silt sizes, less organic matter, and more abundant bioturbation features than thinly-laminated shale. Together, these characteristics indicate an oxygenated environment in more open marine waters which were deeper than the shelf waters where the thinly-laminated shales accumulated. The Java Formation and Angola Member, where the non-banded and lenticularly laminated shales are dominant (Figure 11), are correlative with the thick siltstones and shales of the Brallier Formation to the east which are interpreted as turbidites deposited by westward-flowing paleocurrents (McIver, 1961). The lenticularly-laminated lithotype is very similar in appearance to the "vague turbidite" described by Bouma (1968) from the deeper areas of the Gulf of Mexico. Thus, interpretation of these lithotypes as products of generally deeper water sedimentation of very fine materials carried as distal turbidites appears not unreasonable.

ACKNOWLEDGMENTS

Thanks are due to Jeff Clagett and Jim Florence for cutting the specimen slabs and preparing the negatives. Joe Schwietering provided the stratigraphic correlations. Published by permission of the Director and State Geologist, West Virginia Geological and Economic Survey. Research funded under U. S. DOE contract #EY-76-C-05-5199.

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APPENDIX

Tops of stratigraphic units in wells with partial or complete cores

Linc 1637

Undifferentiated Devonian Shales	2554*
Upper and Middle portion of Huron Member of Ohio Shale	2900
Lower portion of Huron Member of Ohio Shale	3400
Java Formation	3650
Angola Shale Member of West Falls Formation	3760
Rhinestreet Member of West Falls Formation	3824

Jac 1369

Undifferentiated Devonian Shales	2490*
Lower portion of Huron Member of Ohio Shale	3370
Java Formation	3830

Jac 1371

Undifferentiated Devonian Shales	2110*
Lower portion of Huron Member of Ohio Shale	3480
Java Formation	3650

Mas 146

Undifferentiated Devonian Shales	1745*
Lower portion of Huron Member of Ohio Shale	2735
Java Formation	3050
Angola Shale Member of West Falls Formation	3155
Rhinestreet Member of West Falls Formation	3240

Wise 253

Cleveland Shale Member of Ohio Shale	4870*
Three Lick Bed of Ohio Shale	4892
Upper and Middle portion of Huron Member of Ohio Shale	5036
Lower portion of Huron Member of Ohio Shale	5302
Java Formation	5484
West Falls Formation	5560

*Approximate top taken at base of Berea Sandstone or top of Cleveland Shale.